RF Project 1543
Final Report

THE OHIO STATE UNIVERSITY

RESEARCH FOUNDATION

1314 KINNEAR ROAD COLUMBUS 12, OHIO

PHOTOGRAMMETRIC MEASUREMENT OF ICE MOVEMENT
for
GLACIALOGICAL STUDIES
of
THE BYRD GLACIER, ANTARCTIC REGION

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RF Project 1543

FINAL REPORT

by

THE OHIO STATE UNIVERSITY

RESEARCH FOUNDATION

1314 Kinnear Road

Columbus 12, Ohio

To UNIVERSITY OF MICHIGAN
Glacial Geology and Polar Research Laboratory
Institute of Science and Technology

On PHOTOGRAMMETRIC MEASUREMENT OF ICE MOVEMENT

for

GLACIOLOGICAL STUDIES

of

THE BYRD GLACIER, ANTARCTIC REGION

For the period 1 September 1962 - 28 February 1963

Prepared by Ron K. H. Adler
Research Assistant

Date February 1963

FOREWORD

This report was prepared by Mr. R. K. H. Adler, Research Assistant and Miss M. W. Hindman, Research Associate, Department of Geodetic Science, The Ohio State University, under a University of Michigan Project, OSURF Project No. 1543 with Dr. Charles W. M. Swithinbank, Head, Glacial Geology and Polar Research Laboratory, University of Michigan as Project Initiator and Dr. A. J. Brandenberger, Department of Geodetic Science, The Ohio State University, as Project Supervisor.

OSURF Project No. 1543 covers research performed by Dr. Arthur J. Brandenberger, Project Supervisor; Mr. R. B. Forrest, Mr. S. K. Ghosh and Miss M. W. Hindman, Research Associates; and Mr. R. K. H. Adler, Research Assistant.

ABSTRACT

The subject of this research is the measurement of ice movement on the Byrd Glacier in the Antarctic using photogrammetric methods. The work was performed with very limited geodetic control available.

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I. PURPOSE AND SCOPE

The task of this research is the measurement of the ice movement on the Byrd Glacier, based on aerial photography of the glacier taken on two different dates, namely, 10 November 1960 and 24 October 1961.

The photographically recorded changes that have taken place in the planimetric position of various points on the ice surface occurred within a period of approximately one year.

It is desired to measure, within the accuracy attainable with the available data, the magnitude of the ice flow and its direction as a function of time.

The Ohio State University Research Foundation Project No. 1543 covers only the evaluation of changes between the dates on which the two photographic coverages were obtained and is limited in its accuracy by the unfavorable characteristics of the data available, namely, inadequate ground control and rather poor quality of the photography.

II. LOCATION AND DESCRIPTION OF THE BYRD GLACIER

The Byrd Glacier is located in the Antarctic, at approximately 160° East Longitude and 80° South Latitude (see Figs. 1 and 2). The glacier covers a fairly flat valley between two elevated plateaus, about 25 km apart (see Fig. 3). The difference in elevation between the valley and the plateaus is in the order of 1000 m. Ice and snow cover the entire valley. The plateaus are covered by snow with scattered rock protrusions.

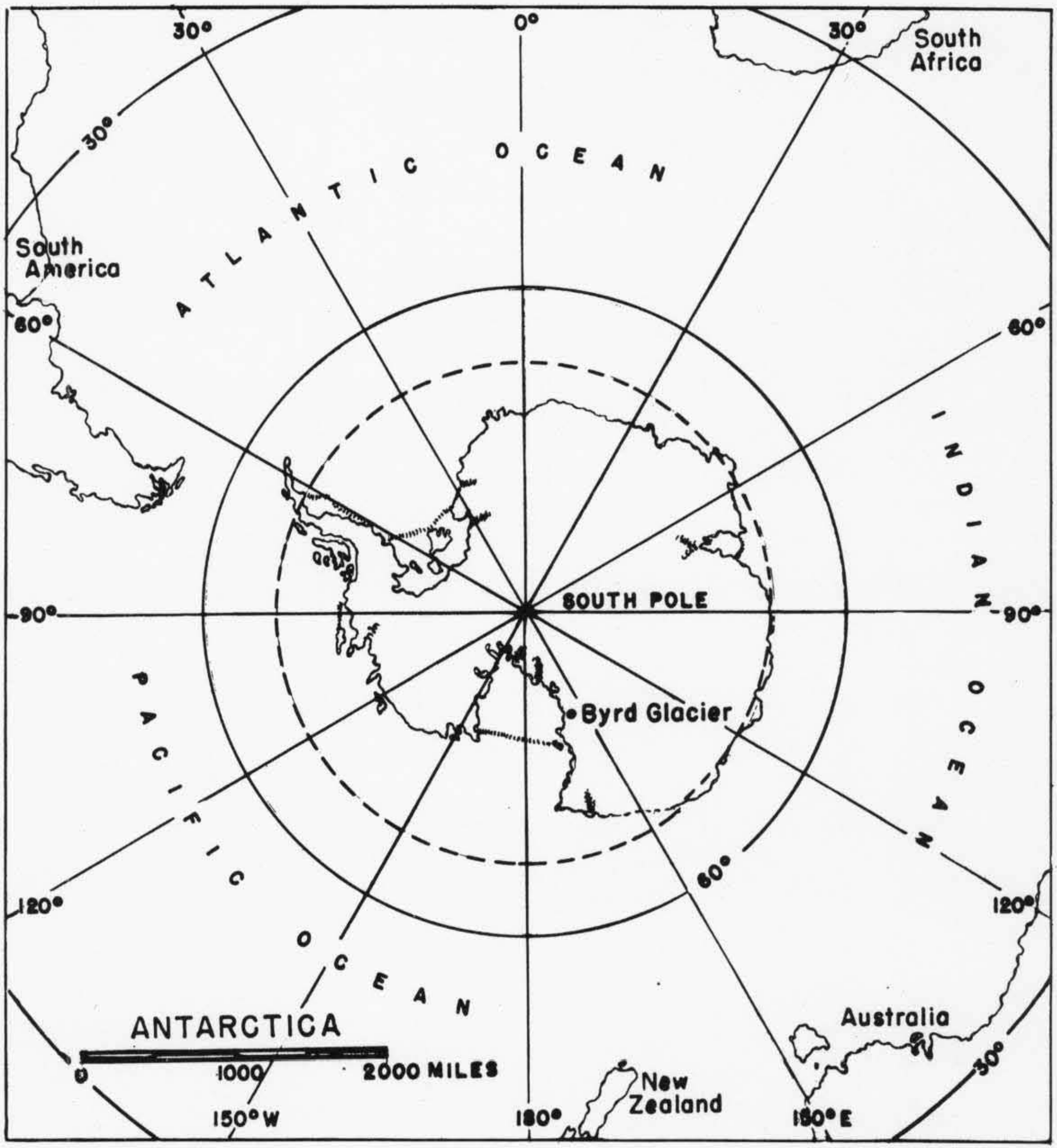

Figure 1. Key Map of the Antarctic

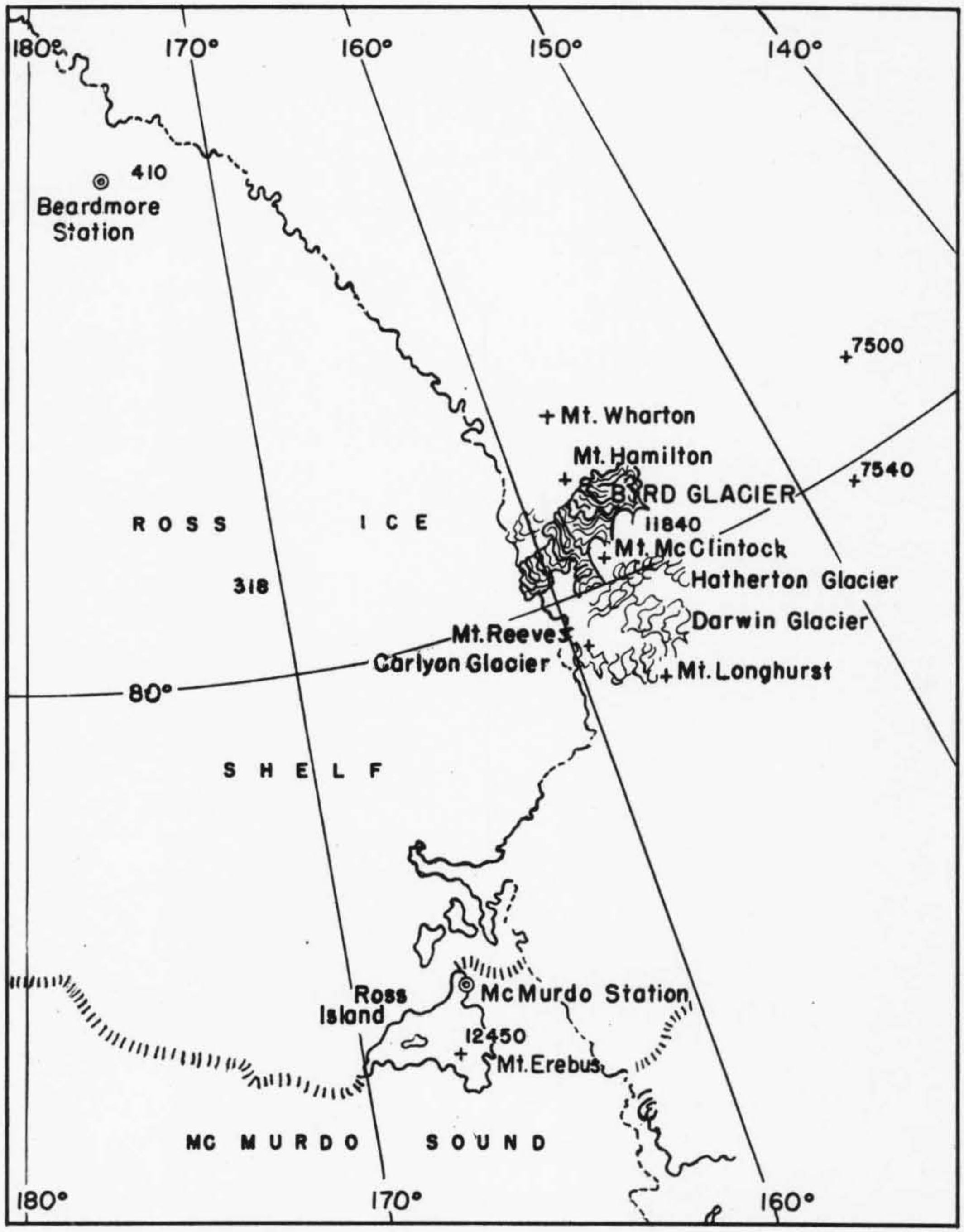

Figure 2. Location of the Byrd Glacier in the Antarctic

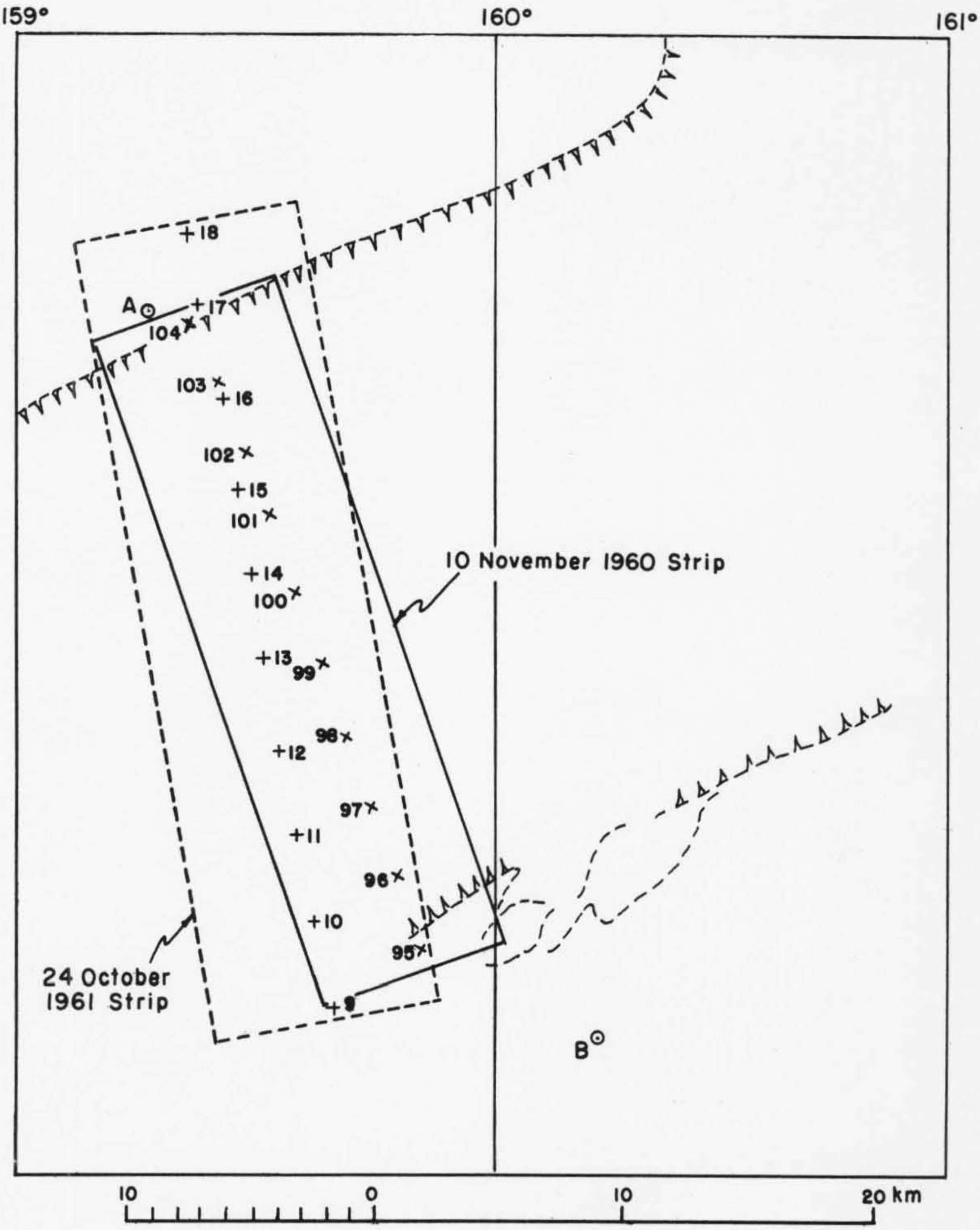

Figure 3. Sketch Showing Vertical Stereoscopic Photo Coverage and Ground Control

III. AERIAL PHOTOGRAPHY

Normally, photographic coverage provided for the purpose of measurement of ice movement should be flown according to strictly pre-planned specifications. It is of great importance that missions flown on different dates should adhere to the same flight lines, use the same camera (or one of very similar characteristics), fly at approximately the same height, and have auxiliary instruments such as altimeter or statoscope, calibrated before each flight. It is also important that photographic coverage should be planned in such a way that existing ground control will be included most advantageously from the photogrammetric point of view. All the above mentioned factors add to the ease and economy of operations and the accuracy of the subsequent results.

The photographic coverage for OSURF Project No. 1543 was provided by using a Trimetrogon arrangement of cameras on each of the two dates, 10 November 1960 and 24 October 1961. This resulted in a vertical photography strip with 60 percent overlap and two oblique photography stirps with lateral overlap of approximately 20 percent. On the 1960 mission the vertical camera used was the T-11, lens serial No. RF 177 camera with a calibrated focal length of 153.84 mm. The average flying height above the glacier, approximately 5,100 m, yielded a photo-scale of approximately 1:33,000. On the 1961 mission the vertical camera used was the CA-14, lens serial No. DF 691 camera with a calibrated focal length of 153.75 mm. The average flying height above the glacier, approximately 6,300 m, yielded a photo-scale of approximately 1:41,000.

Study of the photographic coverage available immediately presented several sources of difficulties:

(1) The two flight lines were flown at an angle to each other,

(2) There was a difference between the flying heights resulting in an appreciable difference in photo-scale,

(3) The altimeter readings, although presumably relatively correct within each strip, did not, apparently refer to the same datum.

(4) Of the two reliable ground control points in the vicinity, only one fell within the vertical coverage and that in only one strip. The other reliable control point was covered by oblique photography, which created an attitional problem of correlating the two different systems.

The disadvantageous location of the very meager ground control made the subsequent photogrammetric operations rather difficult.

IV. FIELD CONTROL

Available field control points were very limited in number. In fact, the only points clearly identifiable on the photographs, with geographical coordinates, tentative elevations, as well as the distance between them provided were A and B (see Fig. 3).

Additional elevation points, nos. 102, 104, 109, 145, 151, 152, C, D, E and F were supplied but of all these only F could be identified on the photographs with some degree of certainty. Consequently, photogrammetric operations were based mainly on points A and B, with point F serving as an auxiliary point. The remaining elevations were used only to obtain an approximate idea of the level of the glacier surface.

For the purpose of referring and transforming the photogrammetric measurements to a ground coordinate system, a geodetic azimuth was computed from geographical coordinates between points A and B and found to be $147^{\circ}\ 18'\ 56''$. Using this azimuth and the known distance AB equal to 34,092 m, a rectangular ground coordinate system was established. With A as the point of origin, the coordinate values X_A = 100,000.0 m and Y_A = 100,000.0 m were given to this point. The Y-axis of this system is positive towards North and the X-axis is positive towards East.

V. PHOTOGRAMMETRIC OPERATIONS

1. General considerations. It was decided to carry out an aerial triangulation across the glacier, using one of the vertical strips, and to transform it to the ground coordinate system, thus establishing a reference strip for the aerial triangulation of the other vertical strip.

   Two aerial triangulations connected to each other by common points and both referred to the same ground coordinate system enabled evaluation of changes in the position of selected points common to both strips.

2. Aerial triangulation. As a preliminary operation the photography was carefully examined and suitable points, identifiable on both strips, selected for measurement within the aerial triangulations. These points were chosen in such a way that they formed three parallel rows across the glacier. At least three points per model were selected with many additional points at the edges of the glacier where the shearing is greatest.

   Auxiliary points were also chosen outside the glacier surface (on the plateaus) to provide means of connecting the two aerial triangulations and transforming them into the system of ground coordinates. Location and numbering of all the selected points were marked on photographic prints.

   Next, altimeter readings were recorded of each set of three simultaneous photographs (one vertical and its respective two obliques) to obtain relative differences in flying height between consecutive air stations.

   These relative differences were transformed into pre-computed bz-components for each model in the two aerial triangulations.

The aerial triangulations were carried out at the Wild Autograph A7 using a "forward and return" technique for the reference strip to test the accuracy of the procedure and to eliminate certain instrumental errors.

In view of inadequate horizontal and vertical ground control, the results of the aerial triangulation technique employed can be considered as quite satisfactory.

The closure errors of the order of $\pm$ 2.5 mm in x and y machine coordinates, and $\pm$ 6 m in z, with a machine scale of 1:20,000, at the end of the "forward and return" procedure allowed a linear adjustment to be made, with the means of the "forward" and "return" readings taken as the final machine coordinates (see Columns 1 and 2, Table I).

3. Transfer of control point B from the oblique to the vertical photography system.

This rather difficult problem was solved by performing an intersection from three isocenters of adjacent oblique photographs which had a common lateral overlap with the vertical reference strip. The intersected location was then connected by coordinatograph measurement to the triangulation system. Any inaccuracy in this transfer procedure would not affect the accuracy of the measurement of relative position changes between the two strips. The effect on absolute position would be negligible since the given distance AB is accurate only to $\pm$ 50 m.

VI. COMPUTATION

The values for the linear adjustment and transformation from machine to terrestrial coordinates of the reference (October 1961) strip are shown in Table I. The only available control points, A (origin of the terrestrial system) and B (transferred from the oblique photography) were used as the basis for computation. Small x and y represent machine coordinates, capital X and Y, terrestrial coordinates.

The second triangulation (November 1960 strip) was transformed and adjusted in a similar manner, (see Table II), but here the points computed in the reference strip and located outside the glacier valley (thus assumed to be immobile) were used as control. Four such points were used at each end of the triangulation, with a center of gravity computed for each group, thus giving a stronger connection between the two strips.

This connection was checked for the purpose of determining the accuracy of the relative position of the points so computed, common to the two strips. Regarding the reference strip as errorless and using eight points outside the glacier as criterion, the following standard errors of terrestrial coordinates were obtained:

$$m_X = \pm 11.2 \text{ m} \quad \text{and} \quad m_Y = \pm 11.9 \text{ m}.$$

Subsequently, the vectorial components of the ice flow (ΔX and ΔY), their resultant (the flow distance), and its azimuth (azimuth of the flow) were computed for each one of the chosen points.

VII. PRESENTATION OF RESULTS

Table I shows the adjusted and transformed coordinates of the reference strip (24 October 1961), the last two columns being the final terrestrial coordinates.

Table II shows the adjusted and transformed coordinates of the strip (10 November 1960), the last two columns being the final terrestrial coordinates.

Table III shows the computed final results of the investigation, namely, the vectorial components of the ice displacement at each point, their resultant (the flow distance) and the azimuths of the flow lines. The attached diagram (Fig. 4) shows the points plotted in their respective positions on 10 November 1960 and 24 October 1961 at the scale 1:50,000. The grid shown is that established for the project with point A as its origin. Azimuths are true, clockwise from the North.

Table I

Transformation and Adjustment of Aerial Triangulation
Photo-Strip of 24 October 1961

$X = by + ax + C_x$ $\quad C_x = 77\ 594.26$

$Y = ay - bx + C_y$ $\quad C_y = 119\ 782.54$

Point	Machine Coordinates		Final Coordinates	
	x (mm)	y (mm)	X (m)	Y (m)
A	1 000.00	1 000.00	99 999.39	100 001.07
	Transferred		Computed from geographic coordinates	
B	2 409.21	1 785.18	118 410.08	71 306.22
1a	856.47	1 357.18	107 345.21	103 497.15
2a	913.37	1 171.30	103 499.03	102 053.10
4a	1 079.68	1 180.13	103 903.46	98 556.65
7a	1 252.15	1 179.50	104 116.42	94 917.87
10a	1 406.95	1 182.62	104 385.30	91 656.72
13a	1 565.99	1 187.24	104 691.39	88 308.10
16a	1 725.24	1 202.02	105 212.06	84 968.38
19a	1 888.40	1 201.74	105 420.18	81 528.43
22a	2 050.42	1 213.40	105 878.68	78 124.19
24a	2 201.32	1 437.67	110 807.23	75 235.41
25a	2 212.59	1 225.37	106 343.91	74 719.19
26a	2 241.13	1 002.84	101 687.46	73 825.27
27a	2 364.30	1 413.54	110 512.06	71 765.98
28a	2 359.69	1 238.32	106 810.04	71 633.36
29a	2 407.48	1 007.52	102 004.39	70 322.54
101	981.57	1 223.80	104 695.90	100 683.41
102	1 036.89	1 235.75	105 020.54	99 532.21
103	1 050.39	1 240.26	105 133.38	99 253.36
104	1 055.35	1 251.05	105 367.47	99 162.89
105	1 074.25	1 240.62	105 172.27	98 750.55
106	1 087.95	1 239.60	105 168.73	98 460.23
107	1 107.04	1 246.72	105 343.95	98 066.90
108	1 140.57	1 254.06	105 542.77	97 369.27
109	1 247.60	1 259.06	105 788.63	95 118.22
110	1 396.55	1 255.46	105 908.10	91 971.64
111	1 520.22	1 300.08	107 011.51	89 421.57
112	1 702.76	1 305.70	107 369.52	85 578.57

Table I (cont'd)

Point	Machine Coordinates		Final Coordinates	
	x (mm)	y (mm)	X (m)	Y (m)
113	1 845.56	1 336.30	108 202.31	82 606.59
114	2 020.79	1 392.23	109 611.93	78 983.78
115	2 103.32	1 418.09	110 265.66	77 276.88
116	2 123.98	1 420.40	110 341.50	76 844.12
117	2 150.19	1 416.43	110 292.13	76 286.06
118	2 172.74	1 410.62	110 199.16	75 802.78
119	2 181.04	1 410.47	110 206.89	75 627.51
120	2 189.11	1 411.76	110 244.69	75 458.97
121	2 198.93	1 406.67	110 150.20	75 245.17
122	2 211.03	1 409.76	110 231.25	74 933.99
201	990.53	1 166.94	103 508.29	100 419.82
202	1 057.66	1 187.14	104 022.43	99 030.33
203	1 072.74	1 173.35	103 751.34	98 694.15
204	1 088.21	1 172.85	103 761.09	98 367.18
205	1 099.75	1 180.50	103 937.59	98 133.80
206	1 120.60	1 184.15	104 041.93	97 698.80
207	1 150.08	1 188.31	104 168.35	97 082.42
208	1 268.81	1 199.50	104 560.15	94 592.69
209	1 411.63	1 196.98	104 694.34	91 576.84
210	1 557.76	1 194.82	104 840.48	88 491.64
211	1 713.41	1 257.57	106 368.27	85 290.79
212	1 855.32	1 281.14	107 051.60	82 328.36
213	2 031.33	1 346.95	108 670.55	78 702.05
214	2 133.37	1 339.70	108 651.58	76 540.18
215	2 153.20	1 338.65	108 655.45	76 120.52
216	2 163.42	1 343.52	108 771.57	75 911.34
217	2 178.03	1 346.88	108 861.62	75 607.58
218	2 192.15	1 345.39	108 848.71	75 307.79
219	2 204.72	1 348.84	108 937.97	75 047.17
220	2 213.73	1 354.30	109 064.96	74 864.27
221	2 301.13	1 345.68	108 997.79	73 009.42
301	1 013.56	1 121.40	102 577.91	99 874.30
302	1 080.95	1 132.02	102 890.33	98 466.76
303	1 094.38	1 122.10	102 698.69	98 170.45
304	1 109.56	1 116.05	102 591.00	97 842.33
305	1 119.72	1 113.30	102 546.31	97 624.41
306	1 139.11	1 118.55	102 682.49	97 222.30
307	1 163.71	1 117.03	102 682.70	96 701.41
308	1 284.66	1 141.55	103 358.58	94 182.34

Table I (cont'd)

Point	Machine Coordinates		Final Coordinates	
	x (mm)	y (mm)	X (m)	Y (m)
309	1 426.24	1 134.31	103 391.59	91 186.45
310	1 561.25	1 166.34	104 244.32	88 380.66
311	1 738.92	1 198.75	105 161.02	84 675.54
312	1 867.10	1 228.80	105 963.03	82 011.22
313	2 040.22	1 301.92	107 732.48	78 455.46
314	2 146.95	1 266.05	107 115.87	76 157.12
315	2 164.93	1 269.15	107 204.85	75 781.93
316	2 175.92	1 266.91	107 172.02	75 547.17
317	2 189.07	1 268.07	107 213.73	75 271.33
318	2 200.41	1 273.20	107 336.82	75 038.85
319	2 216.58	1 278.50	107 469.83	74 704.73
320	2 230.04	1 283.88	107 600.97	74 427.87
321	2 310.00	1 287.45	107 781.16	72 745.93
401	938.43	1 069.47	101 383.47	101 390.92
402	1 035.39	1 071.56	101 555.26	99 348.46
403	1 057.62	1 000.69	100 089.54	98 786.57
I=123	2 289.30	1 430.24	110 795.92	73 369.87
II	2 292.13	1 386.92	109 855.87	73 253.36
III	2 372.42	1 431.73	110 906.39	71 618.56
IV	2 368.21	1 398.25	110 194.66	71 663.44

Table II

Transformation and Adjustment of Aerial Triangulation
Photo-Strip of 10 November 1960

$X = by + ax + C_x$ $\quad a = 7.20237750 \quad C_x = 67070.50$

$Y = ay - bx + C_y$ $\quad b = 18.80090046 \quad C_y = 106509.90$

Point	Machine Coordinates		Final Coordinates	
	x (mm)	y (mm)	X (m)	Y (m)
28a	2 323.66	1 223.70	106 813.04	71 636.55
2b	2 154.94	1 365.14	108 257.05	75 827.34
5b	2 009.11	1 386.56	107 609.45	78 723.35
8b	1 861.22	1 385.40	106 522.48	81 495.46
11b	1 713.33	1 417.38	106 058.57	84 506.26

Table II (cont'd)

Point	Machine Coordinates		Final Coordinates	
-	x (mm)	y (mm)	X (m)	Y (m)
14b	1 566.89	1 429.21	105 226.26	87 344.67
17b	1 421.13	1 432.43	104 236.98	90 108.28
20b	1 268.55	1 447.85	103 427.95	93 087.98
23b	1 121.72	1 464.28	102 679.33	95 966.85
101	938.86	1 641.42	104 692.69	100 680.62
102	1 000.17	1 615.46	104 646.20	99 340.95
103	1 016.00	1 596.86	104 410.51	98 909.38
104	1 025.88	1 610.37	104 735.68	98 820.92
105	1 041.88	1 594.06	104 544.27	98 402.64
106	1 054.24	1 587.96	104 518.61	98 126.33
107	1 076.53	1 588.59	104 690.99	97 711.79
108	1 112.34	1 584.71	104 875.96	97 010.59
109	1 218.84	1 553.78	105 061.50	94 785.52
110	1 365.78	1 503.11	105 167.18	91 657.98
111	1 502.32	1 509.54	106 271.48	89 137.21
112	1 685.57	1 457.46	106 612.17	85 316.85
113	1 836.92	1 449.24	107 453.70	82 376.11
114	2 029.66	1 447.32	108 899.80	78 774.61
115	2 120.77	1 449.86	109 603.76	77 079.95
116	2 141.81	1 447.55	109 711.86	76 667.74
117	2 167.66	1 440.15	109 758.92	76 128.44
118	2 189.03	1 440.10	109 911.90	75 726.30
119	2 196.75	1 441.25	109 989.12	75 589.45
120	2 208.33	1 440.35	110 055.61	75 365.25
121	2 214.59	1 438.17	110 059.70	75 231.85
122	2 228.74	1 436.88	110 137.37	74 956.53
201	929.90	1 581.98	103 510.64	100 420.96
202	998.86	1 547.34	103 356.05	98 874.96
203	1 017.11	1 541.94	103 385.97	98 492.95
204	1 034.13	1 526.97	103 227.10	98 065.14
205	1 048.76	1 526.54	103 324.39	97 786.99
206	1 071.00	1 522.02	103 399.60	97 336.30
207	1 101.74	1 516.12	103 510.07	96 715.87
208	1 221.72	1 487.52	103 836.50	94 254.14
209	1 362.87	1 439.39	103 948.23	91 253.75
210	1 504.68	1 436.26	104 910.75	88 565.05
211	1 681.09	1 406.21	105 616.35	85 031.96
212	1 829.83	1 385.83	106 304.48	82 088.72

Table II (cont'd)

Point	Machine Coordinates		Final Coordinates	
	x (mm)	y (mm)	X (m)	Y (m)
213	2 026.50	1 398.53	107 959.74	78 482.62
214	2 126.94	1 363.16	108 018.15	76 339.50
215	2 146.91	1 359.11	108 085.85	75 934.88
216	2 161.32	1 365.86	108 316.54	75 712.58
217	2 174.93	1 368.68	108 467.59	75 477.01
218	2 189.05	1 371.98	108 631.32	75 235.31
219	2 203.07	1 377.25	108 831.38	75 018.67
220	2 213.79	1 383.12	109 018.95	74 850.41
221	2 300.00	1 350.00	109 017.18	72 991.04
301	938.75	1 528.90	102 576.43	99 872.27
302	1 014.32	1 504.52	102 662.34	98 275.89
303	1 022.85	1 486.89	102 322.32	97 988.54
304	1 034.06	1 466.08	102 081.81	97 627.90
305	1 047.06	1 457.32	102 010.75	97 320.40
306	1 069.09	1 450.96	102 050.04	96 860.41
307	1 093.53	1 440.86	102 035.98	96 328.17
308	1 219.86	1 424.34	102 635.26	93 834.06
309	1 358.13	1 372.10	102 648.97	90 858.21
310	1 503.09	1 360.57	103 476.26	88 049.80
311	1 688.50	1 338.87	104 403.67	84 407.63
312	1 825.39	1 329.49	105 213.26	81 766.42
313	2 021.69	1 350.32	107 018.70	78 225.82
314	2 117.79	1 284.70	106 477.14	75 946.43
315	2 136.92	1,284.67	106 614.35	75 586.56
316	2 147.55	1 280.79	106 617.96	75 358.76
317	2 160.70	1 280.48	106 706.86	75 109.30
318	2 179.79	1 308.13	106 974.87	74 949.54
319	2 192.34	1 300.04	107 302.48	74 655.31
320	2 207.74	1 305.57	107 517.37	74 405.61
321	2 289.45	1 288.40	107 783.06	72 745.72
402	944.80	1 472.40	101 557.75	99 351.59
403	944.92	1 394.15	100 087.44	98 785.74
I=123	2 312.87	1 438.38	110 771.50	73 385.62

Table III

Azimuth and Magnitude of Ice Movement
10 November 1960 to 24 October 1961

Point	Vectorial Components		Resultant Flow Distance (m)	Azimuth
	ΔX (m)	ΔY (m)		
28a	- 3.00	- 3.19	Auxiliary Control Point	
101	+ 3.21	+ 2.79	Auxiliary Control Point	
102	+374.34	+191.26	420.4	62° 56'
103	+722.87	+343.98	800.5	64 33
104	+631.79	+341.97	718.4	61 35
105	+628.00	+347.91	717.9	61 01
106	+650.12	+333.90	730.8	62 49
107	+652.96	+355.11	743.3	61 28
108	+666.81	+358.68	757.2	61 44
109	+727.13	+332.70	799.6	65 25
110	+740.92	+313.66	804.6	67 03
111	+740.03	+284.36	792.8	68 59
112	+757.35	+261.72	801.3	70 56
113	+748.61	+230.48	783.3	72 53
114	+712.13	+209.17	742.2	73 38
115	+661.90	+196.93	690.6	74 17
116	+629.64	+176.38	653.9	74 21
117	+533.21	+157.62	556.0	73 32
118	+287.26	+ 76.48	297.3	75 06
119	+218.77	+ 38.06	222.0	80 08
120	+189.08	+ 93.72	211.0	63 38
121	+ 90.50	+ 13.32	91.5	81 38
122	+ 93.88	- 22.54	30.5	103 30
201	- 2.35	- 1.14	Auxiliary Control Point	
202	+666.38	+155.37	684.2	76° 52'
203	+365.37	+201.20	417.1	61 10
204	+533.99	+302.04	613.5	60 30
205	+613.20	+346.81	704.5	60 31
206	+642.33	+362.50	737.5	60 33
207	+658.28	+366.55	753.4	60 53
208	+723.65	+338.55	798.9	64 56
209	+746.11	+323.09	813.1	66 35
210	- 70.27	- 73.41	Rejected	
211	+751.92	+258.83	795.2	71° 00'
212	+747.12	+239.64	784.6	72 13

Table III (cont'd)

Point	Vectorial Components		Resultant Flow Distance (m)	Azimuth
	ΔX (m)	ΔY (m)		
213	+710.81	+219.43	743.9	72° 51'
214	+819.07	+200.68	843.3	76 14
215	+569.60	+185.64	599.1	71 57
216	+455.03	+198.76	496.5	66 24
217	+394.03	+130.57	415.1	71 40
218	+217.39	+ 72.48	229.2	71 34
219	+106.59	+ 28.50	110.3	75 02
220	+ 46.01	+ 13.86	48.1	73 14
221	- 19.39	+ 18.38	Auxiliary Control Point	
301	+ 1.48	+ 2.03	Auxiliary Control Point	
302	+227.99	+190.87	297.3	50° 04'
303	+376.37	+181.91	418.0	64 12
304	+509.19	+214.43	552.4	67 10
305	+535.56	+304.01	615.8	60 25
306	+632.45	+361.89	728.7	60 13
307	+646.72	+373.24	746.6	60 01
308	+723.32	+348.28	802.8	64 17
309	+742.62	+328.24	811.9	66 09
310	+768.06	+330.86	836.3	65 52
311	+757.35	+267.91	803.3	70 31
312	+749.77	+244.80	788.7	71 55
313	+713.78	+229.64	749.8	72 10
314	+638.73	+210.69	672.6	71 45
315	+590.50	+195.37	622.0	71 42
316	+554.06	+188.41	566.6	71 13
317	+506.87	+162.03	532.1	72 16
318	+361.95	+ 89.31	372.8	76 08
319	+167.35	+ 49.42	174.5	73 33
320	+ 83.60	+ 22.26	86.5	75 06
321	- 1.90	+ 0.20	Auxiliary Control Point	
402	- 2.49	- 3.13	Auxiliary Control Point	
403	+ 2.10	+ 0.83	Auxiliary Control Point	
I=123	+ 24.42	- 15.75	Auxiliary Control Point	

<u>Standard Errors</u>

$m_X = \pm 11.2$ m

$m_Y = \pm 11.9$ m

VIII. DISCUSSION AND RECOMMENDATIONS

The results show decisively the existence of ice displacement on the surface of the glacier which grows in magnitude from the edges toward the center. There also appears to be a general direction of the flow.

The accuracy of position determinations achieved under this project is good in view of the many adverse factors involved. If further investigations of similar nature are to be undertaken in the future, the accuracy can be very significantly improved providing certain aspects mentioned in this report are taken into consideration.

It is recommended that in future investigations photographic coverage should be planned in advance and periodical re-flights made at one year intervals using the same type of camera, the same flying height above the ground, and following as much as possible the same flight lines. The photographs should be exposed at the same time of day and preferably on the same day of the month to obtain as much similarity of conditions as possible. The best results could be achieved if the points on the glacier surface were marked in accordance with recommendations made by Dr. A. J. Brandenberger in connection with various research projects carried out under his supervision in glacier regions.[1,2] The use of an aerial camera with high optical resolution would greatly improve the quality of photography.

Suitable ground control with at least four control points at the beginning and three at the end of the strips with homogeneous horizontal and vertical accuracy, would be desirable when precise absolute and relative flow vectors should be determined.

Periodical evaluations made at planned intervals would be of scientific value in the glaciological field. This, however, would require an extension of the program.

1. A. J. Brandenberger: Mapping Glaciers in Western United States. The Ohio State University Research Foundation Project No. 1227, January 1962.
2. A. J. Brandenberger: Photogrammetric Glacier Mapping for Glaciological Studies in Yukon, Canada. The Ohio State University Research Foundation Project No. 1391, April 1962.

Supervisor *A. J. Brandenberger* Date *Febr. 26* 1963

Executive Director *Oram C Woolpert* *CHS* Date *2/27/6* 1963

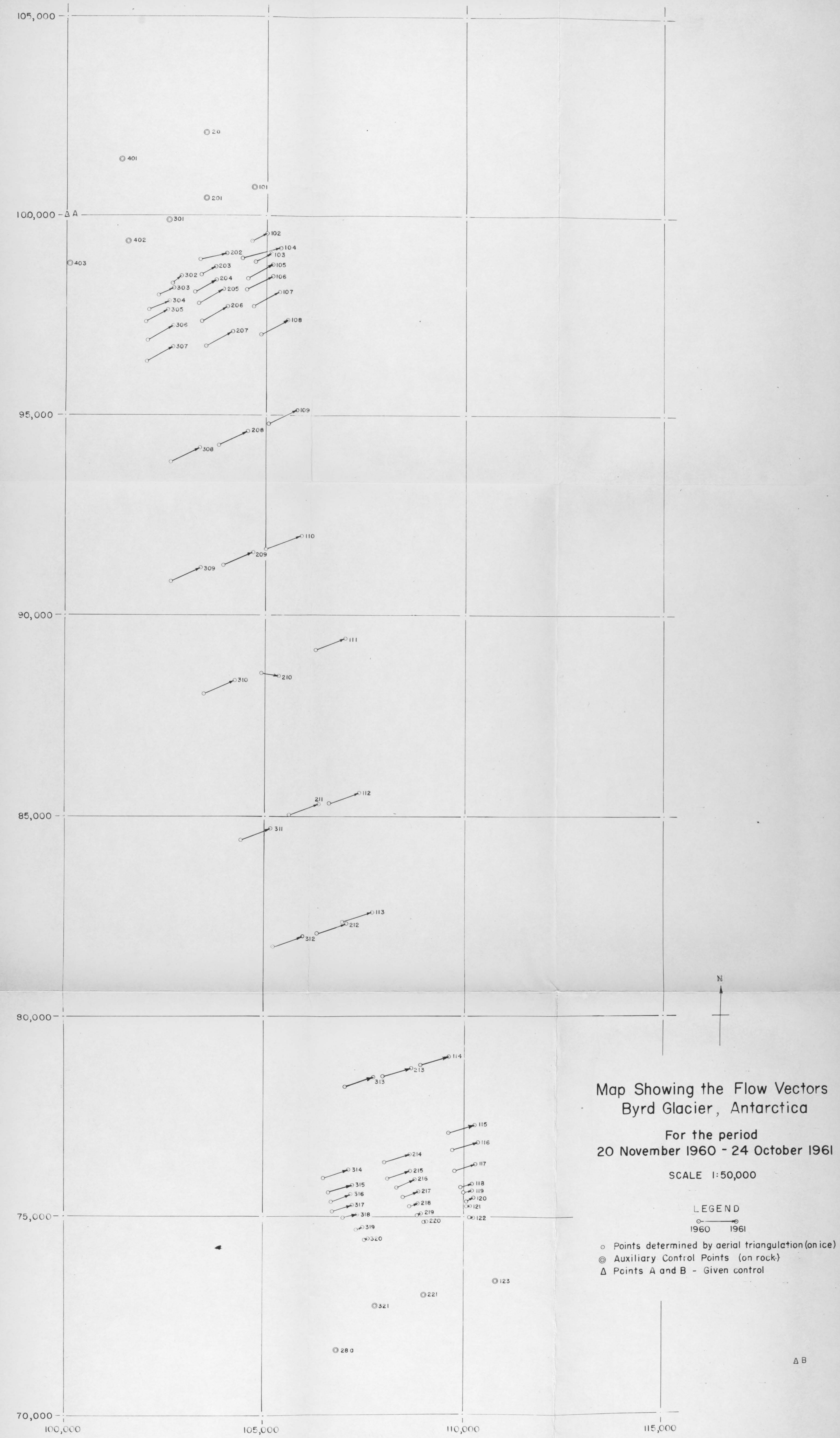
Map Showing the Flow Vectors
Byrd Glacier, Antarctica
For the period
20 November 1960 - 24 October 1961
SCALE 1:50,000
LEGEND
1960
1961
Points determined by aerial triangulation (on ice)
Auxiliary Control Points (on rock)
Δ Points A and B - Given control
N
105,000
100,000
95,000
90,000
85,000
80,000
75,000
70,000
100,000
105,000
110,000
115,000
A
B

Figure 4.